

Dynamical Stability and Galaxy Evolution in LSB Disk Galaxies

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Abstract. We demonstrate that, due to their low surface mass density and large dark matter content, LSB disks are quite stable against the growth of global bar modes. However, they may be only marginally stable against local disk instabilities. We simulate a collision between an LSB and HSB galaxy and find that, while the HSB galaxy forms a strong bar, the response of the LSB disk is milder, in the form of spiral features and an oval distortion. Unlike its HSB counterpart, the LSB disk does not suffer strong inflow of gas into the central regions. The lack of sufficient disk self-gravity to amplify dynamical instabilities makes it difficult to explain strong interaction-driven starbursts in LSB galaxies without invoking mergers.

The lack of companions around low surface brightness (LSB) disk galaxies [1,2] has led to the suggestion that, without the well-established dynamical trigger provided by interactions, LSB galaxies may simply evolve passively due to their low surface densities [3], and never experience any strong star-forming era in their lifetimes. Indeed, sufficient tidally induced star formation in LSB disks may drive evolution from LSB to high surface brightness (HSB) galaxies. This has been suggested as the cause of the observed isolation of LSB galaxies: interactions in denser environments transform them into HSB or HII galaxies or perhaps even destroy them entirely.

However, the ability for interactions to trigger evolution and starburst activity is linked to instabilities in the stellar disk. As LSB disk galaxies have lower disk mass densities and a greater fraction of dark to visible matter than do HSB galaxies [4], the stability of LSB disks – and their response to tidal interactions – may be quite different than that of “normal” HSB galaxies. In this study, we use analytic stability criteria and numerical simulation to investigate the stability of LSB disks in the context of galaxy interactions.

STABILITY CRITERIA

To study disk stability, we use the structural properties of the LSB disk galaxy UGC 128 and the HSB galaxy NGC 2403, derived by de Blok & McGaugh [4] from HI rotation curve decompositions. UGC 128 has a disk mass density nearly an order of magnitude below that of NGC 2403, and is more dark matter dominated: the mass-to-light ratio within 6 scale lengths is $\Upsilon_B = 30$ for UGC 128 and $\Upsilon_B = 7.4$ for NGC 2403 (see [4] for details). The rotation curves for UGC 128 and NGC 2403 are shown in Figure 1a.

One measure of the susceptibility of galactic disks to global bar instabilities is the X_2 parameter [5]: $X_{m=2} = \frac{\kappa^2 R}{4\pi G \Sigma_d}$, where κ is the epicyclic frequency, R is the radius, and Σ_d is the disk surface density. For flat rotation curves, disks prove stable against growing modes if $X_2 > 3$, while for linearly rising rotation curves $X_2 > 1$ is a sufficient condition for stability. Figure 1b shows X_2 as a function of scale length for our representative galaxies. The HSB galaxy NGC 2403 is only marginally stable over a large range of radius, while the LSB galaxy UGC 128 proves stable throughout the disk, due to its lower mass surface density. We point out that the rotation curve modeling assumed maximum disk models; if LSBs are less than maximal disks, they will be even *more* stable.

If LSB disks are stable against the growth of global instabilities in the disks, are they also stable against *local* instabilities? The growth of local axisymmetric instabilities is measured by the Toomre Q parameter [6]: $Q = \frac{\sigma_r \kappa}{3.36 G \Sigma_d}$, where σ_r is the radial velocity dispersion of the disk stars. Lacking information on σ_r in LSB disks, we use two alternatives: 1) that σ_r is like that in the Milky Way (~ 30 km s $^{-1}$) or 2) that $\sigma_r^2 \sim \Sigma_d$ (so that $\sigma_r \sim 11$ km s $^{-1}$). Figure 1c shows Q in each disk; if velocity dispersion drops with surface density as might be expected from energy arguments, LSB and HSB disks may have similar *local* stability properties, such that local instabilities might grow in LSB disks where global modes cannot.

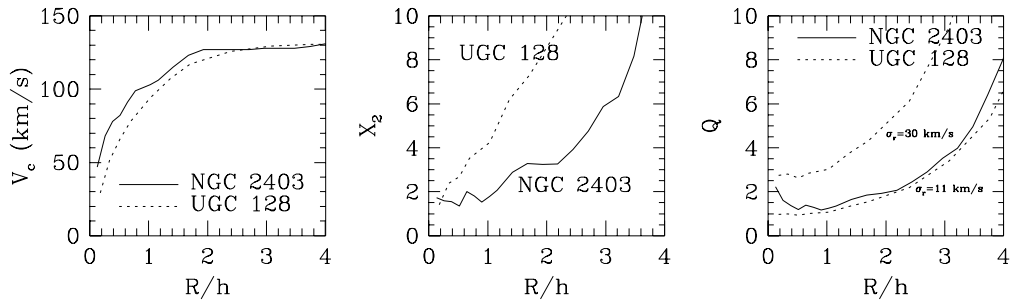


FIGURE 1. Left: Rotation curves of NGC 2403 (HSB) and UGC 128 (LSB), as a function of disk scale length (R/h). Middle: X_2 stability parameter. Right: Toomre Q parameter. The two curves for UGC 128 reflect two choices for σ_r .

NUMERICAL MODELS

To examine how LSB disks will respond to a close interaction, we simulate a grazing encounter between an LSB galaxy and an HSB companion. We choose a prograde, parabolic orbit with a perigalactic separation of $R_p = 10$ disk scale lengths.

Rather than build galaxy models which differ in a number of structural parameters, we focus on variations in disk surface density to define the difference between HSB and LSB disk galaxies. We construct two model galaxies with disk surface densities which differ by a factor of eight, similar to the difference between NGC 2403 and UGC 128. The dark halos have identical mass distributions (as a function of R/h) in both galaxies, resulting in our LSB being very dark matter dominated. We initialize velocities in *both* galaxy disks such that $Q=1.5$, implying lower velocity dispersion in the LSB disk; the simulation is thus a conservative test of LSB stability. In models which include gas, the gas comprises 10% of the total disk mass in each galaxy.

Figure 2 shows the evolution of the HSB and LSB disks in the stellar dynamical interaction model. Both galaxies respond strongly during the close passage (at $T=24$). In the HSB disk, the self-gravity of the disk amplifies the perturbation such that by $T=44$ the galaxy has developed a very strong bar. By contrast, the LSB disk displays a persistent oval distortion and long-lived spiral arms in the disk. Without adequate disk self-gravity no strong bar develops in the LSB disk. Figure 3a shows the strength of the $m = 2$ mode in the inner half mass of each disk. The peak strength is more than twice that of the LSB disk, and declines at late time, probably due to disk heating by the bar. We emphasize that the $m = 2$ mode is not only different in strength between the disks, but also in character: the HSB sports a strong bar, while the LSB displays a milder oval distortion. The bar in the HSB galaxy drives strong inflow (Figure 3b): the gas surface density in the center of the HSB disk has risen significantly by $T=36$.¹ By contrast, the relatively weak response of the LSB disk results in very little change in the gas mass distribution in the disk, even much later after the encounter at $T=72$ (Figure 3c).

LSBS AND GALAXY EVOLUTION

Both analytic arguments and numerical simulation indicate that, despite their seemingly fragile nature, LSB disks are quite stable, and resistant against the growth of bars and bar-driven inflows. These results present a problem for the otherwise appealing notion that interacting LSB dwarfs are the progenitors of HII galaxies experiencing central starbursts [2]. Even the relatively close, strong interaction we have presented will not result in a strong central starburst, nor will it

¹⁾ At this point, the gas was “switched off” in the HSB to save computational expense; however, inflow was ongoing, and the final gas density at the center of the HSB would be even higher than shown here.

drive strong structural evolution in the galaxy; in order to provoke a violent enough response in the LSB disk, a bona-fide merger may be necessary.

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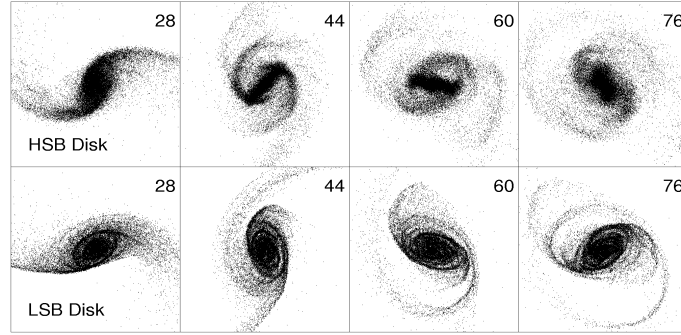


FIGURE 2. Post collision disk evolution. Top: HSB disk. Bottom: LSB disk. Each frame is 10 scale lengths on a side, and time is given in the upper right. One rotation period is approximately 13 time units.

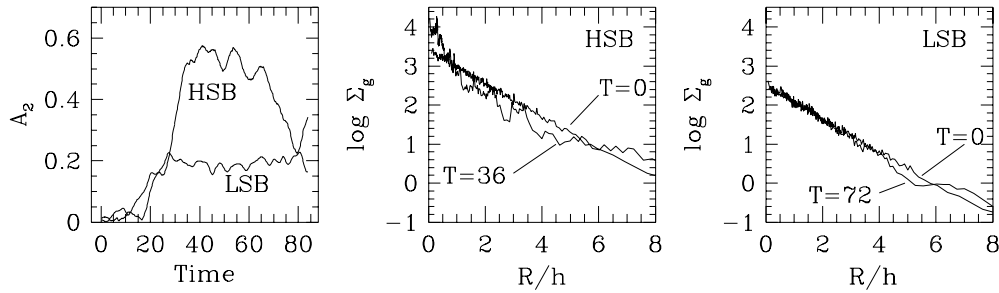


FIGURE 3. Right: Growth of $m=2$ modes in stellar-dynamical simulation. Middle: Gas mass profile in HSB disk in stellar+hydro simulation. Right: Gas mass profile in LSB disk in stellar+hydro simulation.